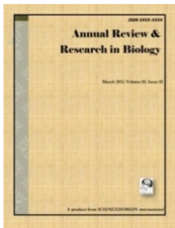

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Modeling of the Effect of Backpack Load Position on the Lumbar Spine Curvature

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Authors' contributions

Authors MA and KL designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors HGB, MK and MA managed the analyses of the study. Author AB managed the literature searches. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

Aims: The aim of the study was to propose a simulated model for predict the lumbar spine curvature in standing from a healthy subject with a loaded backpack.
Study Design and Methodology: The anthropometric data of a schoolboy were used, and then the model was built in BRG. Life MOD (ver. 2007, Biomechanics Research Group, Inc., USA) based on these data. The backpack was loaded at 10, 15 and 20% of subject's Body weight (BW) (stage 1). Then, three boxes (4, 4 and 12 Kg in weight) were attached in the backpack (stage 2). They were arranged in the sagittal, frontal and transversal planes and the position of the heavier weight was changed at each phase.
Results: Regression analysis between our numerical predictions of stage 1 and similar experimental literature led to a correlation gradient of 0.88 and 0.91 for L3-S1-horizon and T12-L3-S1 angles, respectively. The predicted G and H angles peaks at stage 2 were observed when the heavier box was in frontal plane at left or right side.
Conclusion: This study demonstrated the feasibility of obtaining a range of variable boundary conditions (e.g. altered due to changing the location of the heavier box) and

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applying a simplified three-dimensional model that can predict lumbar spine curvature changes in relatively short solution time.

Keywords: Backpack load placement; backpack modeling; lumbar spine curvature.

1. INTRODUCTION

Backpack users mostly are students, military soldiers, mountain climbers, rescue workers, recreational hikers. The average load usually moved by students is 22%of their (BW) [1]. Naturally more than 1/3 of young students can carry more than 30% of their BW. But heavier loads for longer times are usually conveyed in industrial, military as well as recreational applications [2]. Most of the previous studies have been about school backpacks that were done empirically [1,3,4,5]. Chow et al. [1] measured spinal curvature of a male student while normal upright stance without a backpack and during carrying an adapted backpack loaded at 10, 15 and 20% of their bodyweight. Reid et al. [3] applied lateral stiffness rods to the backpack and observed that these lateral stiffness rods cause to transfer 14% of the vertical load from the shoulders to the hips. Singh and Koh [4] investigated the impact of backpack load carriage and its vertical position on the back. Their results showed that placing load low on the back influenced the spatiotemporal parameters more than when loads were located high on the back [4]. Southard et al. [5] study has brought about some significant harness design enhancements that decrease trunk muscle fatigue, exertions in addition to improve comfort totally. Currently, experimental methods are typically used to determine biomechanical behaviors. However, such techniques are difficult, expensive, and sometimes have risks connected to them [6]. Numerical methods, although, have the potential to determine them removing the need for experimental procedures.

It was reported that carrying heavy backpacks might result in changes in trunk posture and finally lower back pain (LBP) [7]. Also prolonged carrying of backpacks affects the fluid content of the intervertebral discs [8]. The Most significant parameters were studied before, include: the type of backpack and its design [2,9,10], different weights of that [1], location of its' center of gravity (COG) [11,12,13],lateral stiffness elements in the suspension system of a backpack [5,14], backpack harness system [5,15], spinal muscles activities [2,7] musculoskeletal symptoms (especially trunk posture) [1,7,8,16,17],physiological parameters [13], maintaining balance [10] and comparison of static and dynamic stages [4].

The purpose of this study is to investigate and propose a simulated model for predict the lumbar spine curvature in standing from a healthy subject with a loaded backpack. Firstly, the backpack is loaded at 10, 15 and 20% of subject's BW (stage 1). Secondly, three boxes (4, 4 and 12 Kg in weight) were attached in the backpack (stage 2). They were arranged in the sagittal, frontal and transversal planes and the position of the heavier weight was changed at each phase.

2. METHODOLOGY

The model was included the anthropometric data of 15.2 years old boy (1.6 m height, 58.9 kg weight).Then an adapted school backpack was applied to the model (Fig. 1). The BRG Life Mod software version 2005 was applied to make a model and to perform the analysis. The software divides the spinal column into thoracic, cervical and lumbar parts and connects these three parts by joints. Respecting to the exactness required in investigating the spinal alignment, the simulating of vertebrae has been executed to make the definition of joints between the vertebrae possible. For all body joints, except for intervertebral disks, the standard hybrid III values were used. To create the desired range of motion (ROM) and stiffness for vertebral column, the natural ROM and the joint damping coefficient of the joint were input [17].

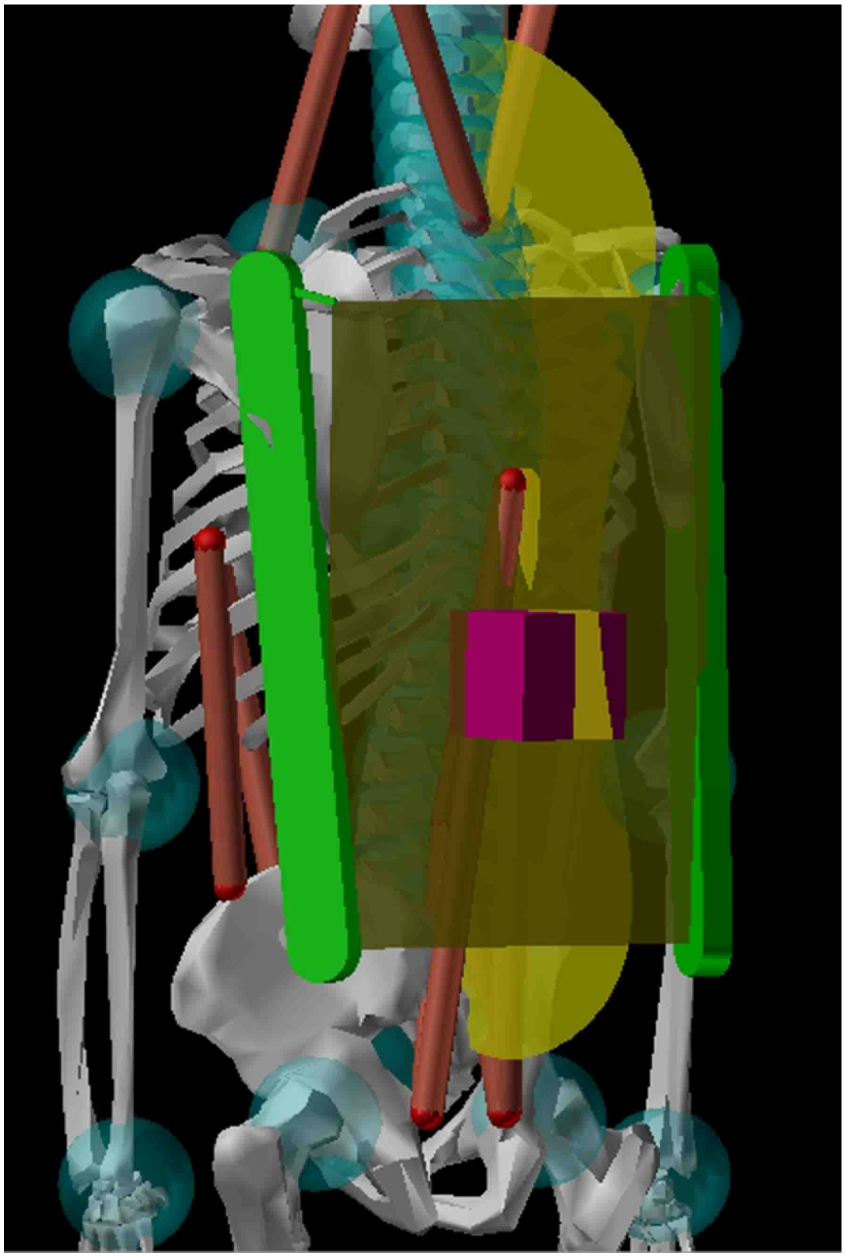


Fig. 1. The model of subject with a backpack

2.1 Design of Modeling and Boundary Conditions

Simulation was done at two stages. At stage1, loading of backpack was modeled at 10, 15 and 20% of boy`s BW by applying two single forces at the location of shoulder straps symmetrically. Initially a backpack frame was built by passing a spline next to the vertebrae mass centers (T2 tillL5) on sagittal plane and a poly-line adds perpendicularly on frontal plane, then in MSC ADAMS version 2005 these two frames were merged to one unit frame (Fig. 1). Hence, massless backpack frame were made of aluminum (density: 2740 kg/m3, young's modulus: 7.1705e+010 N/m2, Poisson's coefficient: 0.33). Finally, the backpack was fixed in shoulders. The cubic volumes in MSC ADAMS 2005 were used to apply the load in the backpack. A box was attached to the backpack frame adjacent to T12 by fixed joint. At Each phase the box was weighed in 10%, 15% or 20% of the boy`s BW.

At stage2, the backpack included a weight within that is distributed in three boxes; they were 4, 4, and 12 kg in weight. These boxes attached to the backpack frame in three phases. At each phase, boxes were arranged in parallel to the sagittal (Fig. 2a), frontal (Fig. 2b), and transversal (Fig. 2c) planes. In all phases, the location of the heavier box (12 Kg) was changed to assess probable effects on the lumbar angle. Thus totally nine cases were examined. Table 1 provides the relevant abbreviations of the heavy box location (12 Kg) in each plane related to its arrangement.

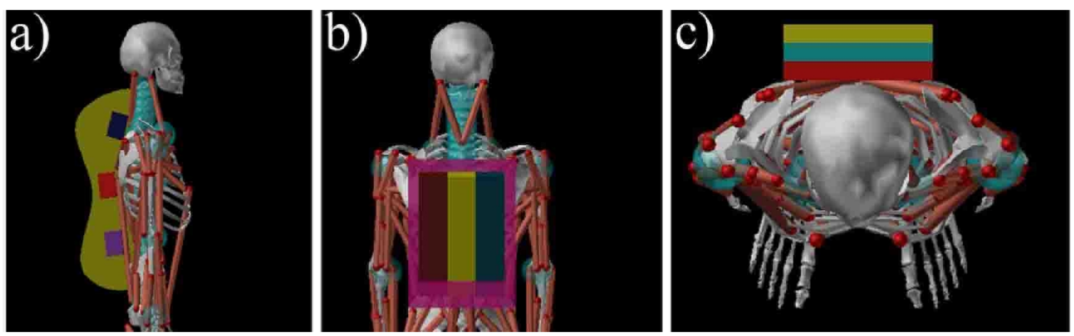


Fig. 2. The model with weights located on sagittal, frontal and transverse plans

2.2 Lumbar Spine Curvature Measurements

Definition of various angles for the quantification of lumbar spinal curvature was done by introducing subject specific G and H angles. They were measured between three adjacent markers as the curvature for the load at the mentioned above stages and the angles are predicted at range of loading. G Angle is calculated between three adjacent markers (T12-L3-S1). H angle is also calculated between three adjacent markers (L3-S1-horizon).

Table 1. Abbreviations for the position of heavier box (12 Kg) at different plans

Plane	Sagittal			Frontal			Transverse		
Heavier box position	In top of two other boxes	In the middle of two other boxes	In bottom of two other boxes	In left of two other boxes	In the middle of two other boxes	In right of two other boxes	The nearest box to the body	In the middle of two other boxes	The farthest box to the body
Abbreviation	ST	SM	SB	FL	FM	FR	TN	TM	TF

3. RESULTS

The computations were done for both above stages for subject specific G and H angles. This also would be considered that due to several phases of both stages, we applied related abbreviations of them (Table 1) in which the angles were computed. For instance, abbreviation of ST refers to the case that the heavier box (12 kg) is located at top of two other boxes (4 and 4 kg) and in this case the lumbar spine curvature is assessed with computation of G and H angles (see section 3.2). Moreover, simulation at stage 1 was done for comparison the gained numerical results (see section 3.1) with the prior similar literature. This comparison was done for probable validation (see section 4.2). The results of stage 2 (see section 3.2) are to predict of the lumbar spine curvature from proposed simulated model.

3.1 Investigation of G and H Angles Changes Due to Variation in Load (Stage 1)

The G angle was decreased with increasing load (Table 2, Fig. 3). It was ranged from 28.1 to 24.8 degree when load was changed from 0 to 20% of BW. The mean slope of G angle changes to load variations was about -18.343 (degree/N) and the y-axis intercepts of that was 80.289 (degree). The percentage reduction of G angle was roughly 11.7.

The H angle was decreased with increasing load (Table 2, Fig. 3). It was ranged from 79.1 to 75.8 degree when load was changed from 0 to 20% of BW. The mean slope of H angle changes to load variations was about -19.486 (degree/N) and the y-axis intercepts of that was 29.417 (degree). The percentage reduction of G angle was roughly 4.2.

The relationship between G and H angle was shown in Fig. 4. A good correlation was determined using a quadratic polynomial equation, for our numerical simulations.

3.2 Investigation of G and H Angles Changes Due to Variation in Load Arrangement (Stage 2)

The Table 3 gives information on the prediction of lumbar angles, included G and H, when the location of heavy box was changed at each plane. As provided in Table 3, in sagittal plane, when the heavy box was located at top of the other boxes (SM), the G angle was calculated 23.9 degree. This is the biggest calculated G angle in sagittal plane as compared to prediction of that in ST (23.2 degree) and SB (22.9 degree) stages.

In frontal plane, when the heavy box was located at the middle of the other boxes (FM), the G angle was calculated 24.4 degree (Table 3). This is the least calculated G angle in frontal plane as compared to prediction of that in FL and FR stages which in both of them the same G angle of 25.1 degree was calculated.

In transversal plane, when the heavy box was located at the TF stage, the G angle was calculated 24.6degree (Table 3). This is the biggest calculated G angle in transversal plane as compared to prediction of that in TN (24.1degree) and TM (24.4degree) stages.

As provided in Table 3, in sagittal plane, when the heavy box was located at the middle of the other boxes (SM), the H angle was calculated 74.4 degree. This is the biggest calculated H angle in sagittal plane as compared to prediction of that in ST (73.4 degree) and SB (72.9 degree) stages.

In frontal plane, when the heavy box was located at the middle of the other boxes (FM), the H angle was calculated 75.1 degree (Table 3). This is the least calculated H angle in sagittal plane as compared to prediction of that in FL and FR stages which in both of them the same G angle of 76.0 was calculated.

In transversal plane, when the heavy box was located at the TF stage, the H angle was calculated 75.4 degree (Table 3). This is the biggest calculated H angle in transversal plane as compared to prediction of that in TN (74.7 degree) and TM (74.1 degree) stages.

Table 2. The lumbar spine angles at different backpack loads. Note, BW refers to Body weight

ANGLE	0% OF BW		10% OF BW		15% OF BW		20% OF BW	
	chow et al.(2007) findings	present study	chow et al. (2007) findings	present study	chow et al. (2007) findings	present study	chow et al. (2007) findings	present study
G (T12-L3-S1)	21.6	28.1	18.9	27.3	18.2	25.9	17.8	24.8
H (L3-S1-HORIZON)	76.9	79.1	75.1	78.9	74.3	77.1	73.2	75.8

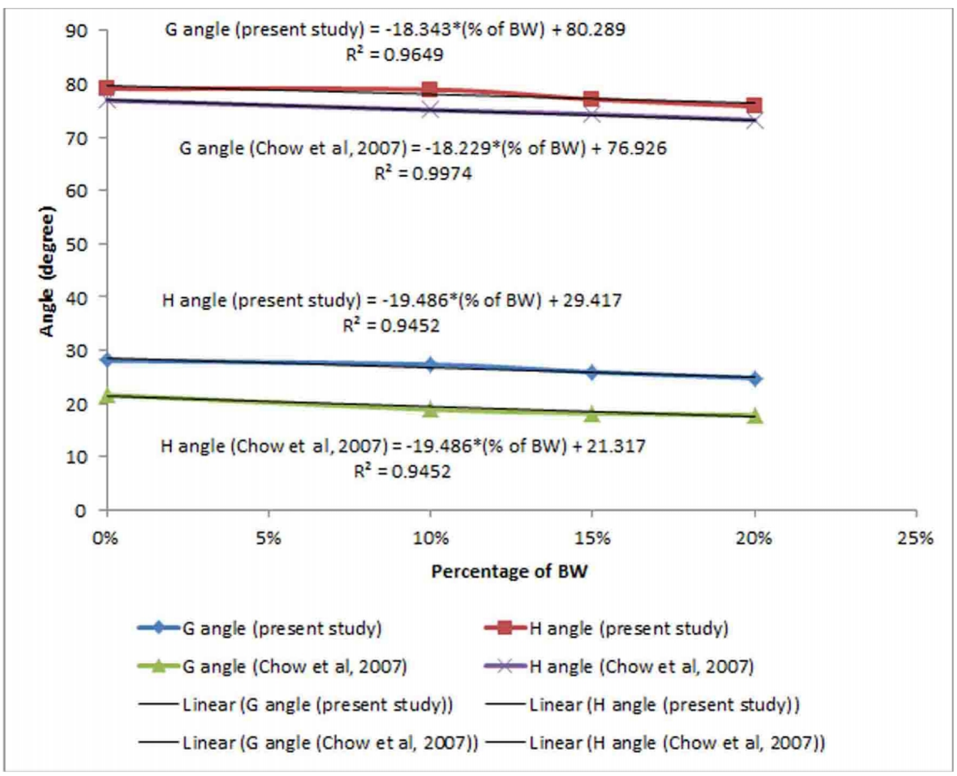


Fig. 3. G (L3-S1-horizon) and H (T12-L3-S1) angles changes due to variation in amount of backpack load.

Table 3. The lumbar angles at different location of heavier load (12 Kg) in sagittal, frontal and transverse planes

Location of heavier load	ST	SM	SB	FL	FM	FR	TN	TM	TF
G ANGLE (T12-L3-S1)	23.2	23.9	22.9	25.1	24.4	25.1	24.1	24.4	24.6
H ANGLE (L3-S1-HORIZON)	73.4	74.4	72.9	76.0	75.1	76.0	74.1	74.7	75.4

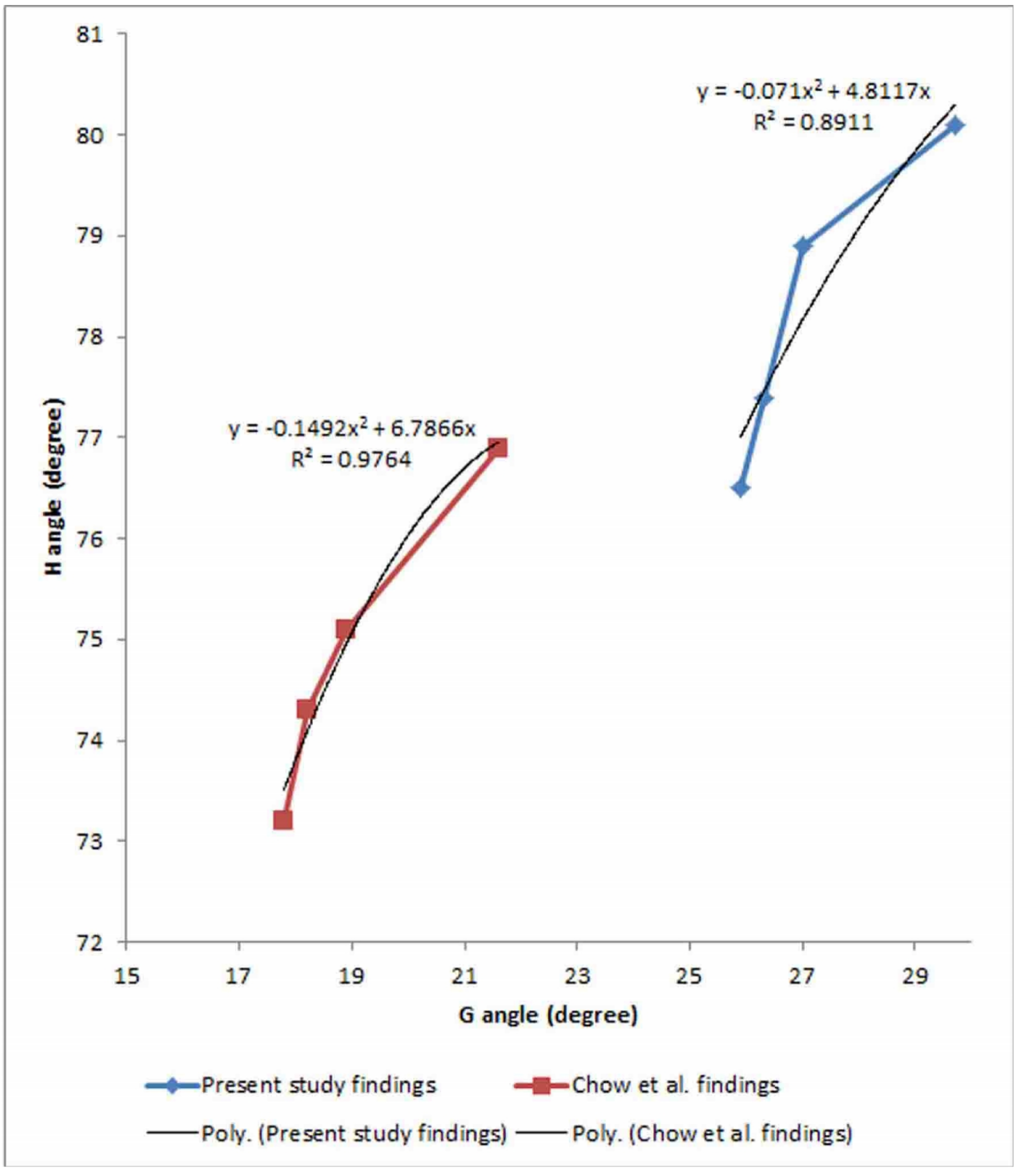


Fig. 4. The relationship between G (L3-S1-horizon) and H (T12-L3-S1) angles

4. DISCUSSION

4.1 Study Findings

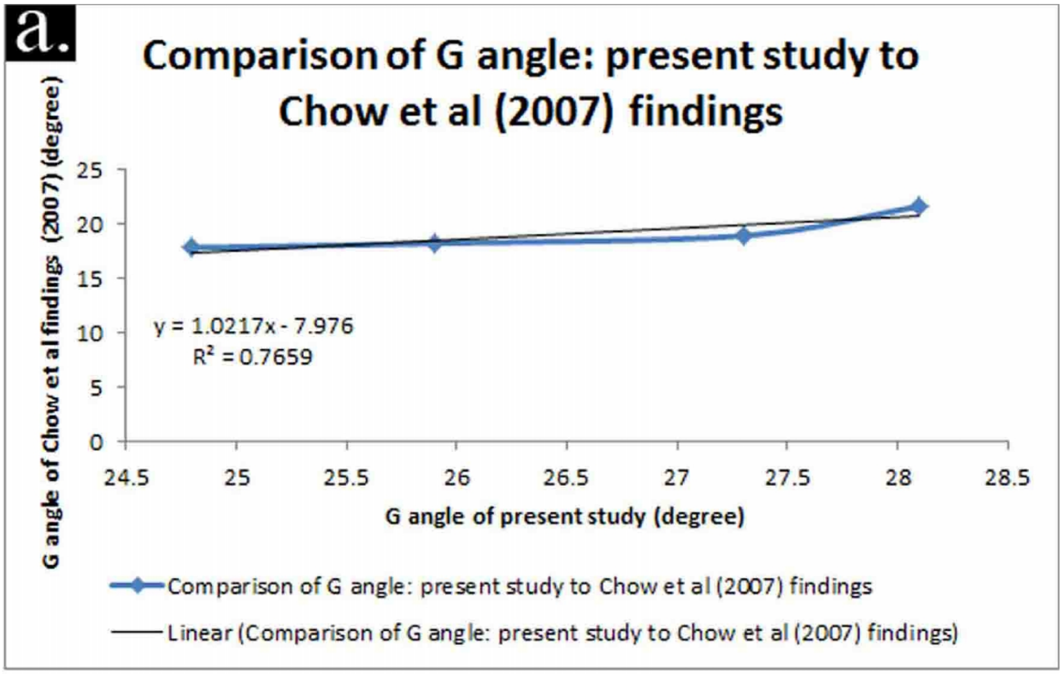
The study has used Numerical model to calculate the lumbar spine curvature in standing from a healthy subject with a loaded backpack. To our knowledge this is the first time that lumbar spine curvature has numerically been examined. Firstly, the backpack was loaded at 10, 15 and 20% of subject's BW (stage 1). This was resulted in G and H angles reduction by about 3.3 degree. Chow et al. [1] found these changes about 3.75 degree. Our numerical model led to a good G angle correlation with the previous similar literature values ($r = 0.88$), in addition a good correlation ($r = 0.91$) was achieved for H angle. These good correlation factors between our numerical method and previous experimental study can validate our simulation technique. Secondly, three boxes (4, 4 and 12 Kg in weight) were attached in the backpack (stage 2). They were arranged in the sagittal, frontal and transversal planes and the position of the heavier weight was changed at each phase. The G angle peaks were observed at stages of SM (23.9 degree), FL (25.1 degree), FR (25.1 degree) and TF (24.6 degree).Similarly, The H angle peaks were observed at stages of SM (74.4 degree), FL (76.0 degree), FR (76.0 degree) and TF (75.4 degree). Also, the most reduction in lumbar angle is observed at incorrect backpack carrying methods at SB case that this means flattening in lumbar lordosis. Despite the use of a simplified model, our predicted values of G and H angles changes were approximately to within 88% of the values of experimental-measured reported in the literature [1]. The numerical model reliably predicted lumbar spine curvature over a range of different loads. Predictions of around 88% of experimental measurement [1] would present limitations in clinical use, therefore, linear correlations have been used. This enables estimations derived from our simulation to be obtained which are highly accurate (e.g. $r = 0.88$ and 0.91 for G and H angles, respectively).

This study demonstrates the feasibility of obtaining a range of variable boundary conditions (e.g. altered due to changing the location of the heavier box) and applying a simplified three-dimensional model that can predict lumbar spine curvature changes in relatively short solution time.

4.2 Comparison to Literature and Validation

Following a literature search we have not found a previous comparable numerical study that used numerical approach to predict lumbar spine curvature at different conditions of loading. In our study, subject specific G and H angles, measured between three adjacent markers as the curvature for that load, were predicted at a range of loading. However, our study compares well to the experimental study used to predict lumbar spine curvature for a subject in standing with a loaded backpack.

Regression analysis between our numerical predictions and similar previous literature [1] led to a correlation gradient of 0.88 and 0.91 for G and H angles, respectively (Figs. 5a and 5b). Therefore, there was a strong correlation between the two methods and similar values were predicted. These regression analysis enable true values to be calculated from predicted model data (using the equations provided in Figs. 5a and 5b). As can be seen in Fig. 3, there is a linear relationship between changes of our predicted G and H values and the changes of percentage of BW. This is in good agreement with the Chow et al. [1] findings. However, the mean differences of 3.4 and 8.1degree are observed for G and H angles values respectively.



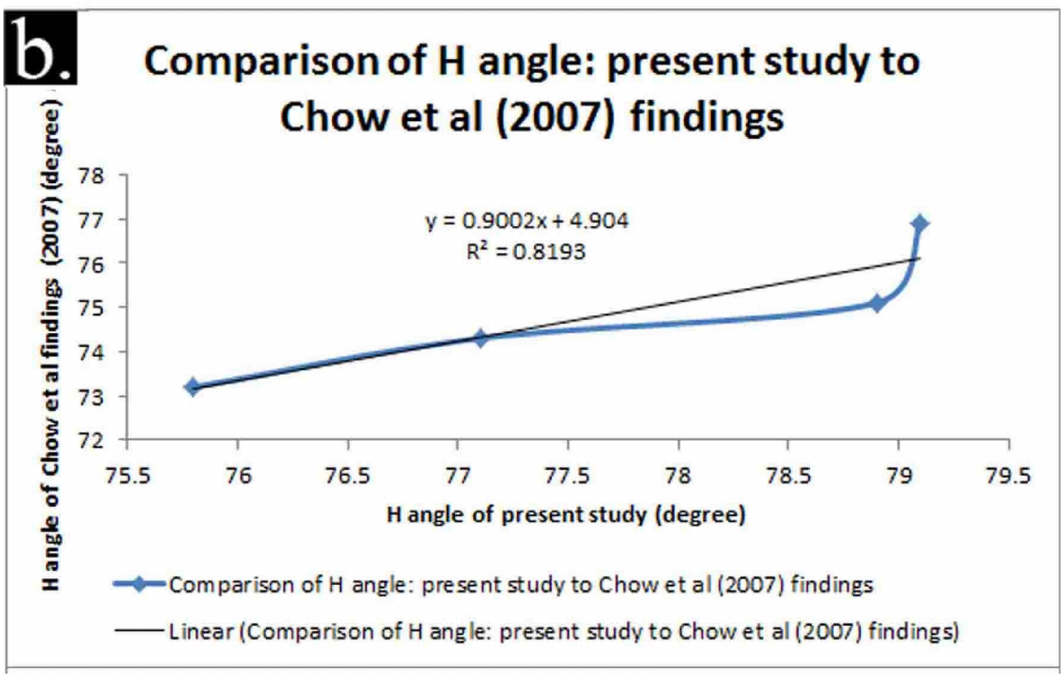


Fig. 5. Regression analysis between numerical predictions of and similar previous literature for G (L3-S1-horizon) (Fig. 5a) and H (T12-L3-S1) (Fig. 5b) angles

As shown in Fig. 4, the relationship between G angle and H angle of our numerical simulation has a good correlation which was calculated using a quadratic polynomial equation. This also is in good agreement with Chow et al findings [1] (Fig. 4). Stuempfle et al. [13] reported that double pack could be more physiologically efficient technique but is not easy enough. Head-loading and back-loading were compared and the results showed that whilst back-loading were mostly associated with more areas of discomfort than head-loading [18]. As noted by Motmans et al. [2], with a load on the back, the combined center of gravity of the trunk plus the backpack shifts backward. This creates an extension moment [19]. In order to counterbalance the weight on the back, a Trunk forward lean occurs [2,4,7,20,21,22,23]. A forward displacement can already be seen with loads less than 10% BW [16]. All these are in agreement with our results in the region of lumbar spine. Grimmer et al. [16] reported that when backpack was positioned at T7 level produced the largest trunk forward lean that is in good agreement with our results when heavy box was located in SM. However, low load placement resulted in greater postural adaptations than high load placement [22]. Chow et al. [1] examined the effect of increasing backpack load on the spine alignment and observed increasing trunk forward lean (TFL) with increasing backpack load. Stuempfle et al. [13] found that electromyography activity of the erector spinae and trapezius were significantly lower when the load was located high on the back. Devroey et al. [12] reported more postural changes at lumbar spine in dynamic load carrying than in static condition. It was reported that the erector spinae EMG activity decreases in carrying backpack, in contrast, rectus abdomen is EMG activity increases [2,7]. Southard et al. [5] indicated that putting a hip belt in a framed backpack may transfer about 30% of backpack vertical force to the hip.

Nevertheless, Stuempfle et al. [13] proposed high load placement (ST) considering physiological factors and muscle activities that is in contrast to our findings at stage 2. Lots of articles have found that backpack`s COG should be as close as possible to trunk due to the least load momentum, energy consumption and spine displacement as well as maintain balance [2,12,13,24]. This is in agreement with our results in Transversal plane.

4.3 Limitations and Future Trends

We only have reported the lumbar spine curvature. This is mainly because that review of the surveys shows the importance of LBP on adolescents and its relation to the load carrying [25]. Hence this study focused on lumbar region to be paid more attention to it. Motmans et al. [2] concluded that, reduced erector spinae EMG activity and increased rectus abdomen is muscle activity in backpack carrying are disproportionate and asymmetric with increasing backpack load and Finneran et al. [26] remarked that such condition is similar to acute or chronic LBP patients.

Korovessis et al. [27] researched the relevance of backpack carriage with anthropometric parameters (gender, height, weight) scoliosis, kyphosis in thoracic, lordosis in lumbar and sports activities; also its effect on LBP and Dorsal Pain (DP) in children and adolescents between 9-15 years old. After investigating the influence of various factors on LBP he stated that there are many potential impacts on spine symptoms so discovering the direct causal relevance between load carrying and LBP is difficult. But Goh et al. [21] perceived Disproportionate increment in lumbosacral joint force during walking with a backpack. Considering different factors, Korovessis et al. [27] are not very farfetched but the effect of carrying backpack on LBP cannot be ignored specially in adolescents whose spine is growing and getting stronger [22,25].

A 15 years old boy was selected for modeling on account of growing spine at this age which is formable with personal habits and they are nonetheless an ‘at-risk’ group as well [1]. Also, Korovessis et al. [27] obtained the most LBP prevalence for 15 years old boys. But it should be noticed that children findings cannot be generalized to adults [16]. Furthermore, Hong Y and Li (2005) surveyed the role of age difference in trunk kinematics at different loads of 6-12 years old children, perceived larger TFL amplitude in 12 years old children [28]. Gender influence should be notified in the future as well; according to results of Korovessis et al. [27], girls experienced more LBP and DP than boys. Reviewing the scientific research reveals the importance of changes in any part of spine in carrying backpack which should be notified in subsequent studies. This study was carried out in static condition and the impact of time and consequent fatigue was ignored.

5. CONCLUSION

We have proposed a simulated model of lumbar spine which was able to reliably predict the lumbar spine curvature in standing from a healthy subject with a loaded backpack. Strong correlation were determined for our prediction and similar experimentally literature (R = 0.88 for G angle and R=0.91 for H angle) which enables correction of the numerical values predicted using regression equations. The model developed was used to make predictions while the backpack was loaded with three boxes (4, 4 and 12 Kg in weight) arranged in the sagittal, frontal and transversal planes and the position of the heavier weight was changed at each phase. The G and H angle peaks were similarly observed at stages of SM, FL, FR and TF. The most reduction in lumbar angle is also observed at incorrect backpack carrying postures in SB. The advantage of using a simple model was the relatively quick solution time.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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